Noncompressible Torso Hemorrhage

A Review with Contemporary Definitions and Management Strategies

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KEYWORDS

- Noncompressible torso hemorrhage • Trauma surgery • Military surgery
- Damage-control surgery • Damage-control resuscitation

KEY POINTS

- Vascular disruption with concomitant hemorrhage is the leading cause of potentially preventable death in both civilian and military trauma. If this occurs in the torso or in a junctional area, it is termed noncomressible torso hemorrhage (NCTH).
- Although the concept of NCTH is intuitive, there remains no formal definition by which to characterize the scope of the problem and compare interventions.
- A novel and inclusive definition using anatomic, physiologic, and procedural criteria enables the identification of patients with NCTH.
- Management requires rapid intervention including damage-control resuscitation and surgery with an emphasis on early hemostasis.
- Despite the emergence of new strategies such as damage-control resuscitation and adjuncts such as endovascular surgery, the principles of proximal and distal vascular control are essential.

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INTRODUCTION

Vascular disruption with hemorrhage remains a leading cause of death in both civilian[1,2] and wartime trauma.[3,4] Broadly classified, hemorrhage occurs from either compressible sites, meaning those locations amenable to immediate control with manual pressure or tourniquet application, or from noncompressible sites, meaning locations not amenable to control with direct pressure or tourniquet application (**Fig. 1**).[5] In the civilian setting, hemorrhage is present in 15% to 25% of admissions, and studies from the wars in Afghanistan and Iraq show that the rate of vascular injury in combat is approximately 10%.[4–6] Although extremity injury is overall most common, the focus of this review is on the management of vascular disruption and hemorrhage from sources within the torso, including the thorax, abdomen and pelvis, once these patients reach definitive care. An excellent review of the prehospital management strategies for these injuries is provided by Kerby and Cusick elsewhere in this issue.[7]

HEMORRHAGE AS A PROBLEM IN TRAUMA

Control of bleeding from vascular disruption within the torso is not readily amenable to control with direct pressure and is therefore referred to as noncompressible torso

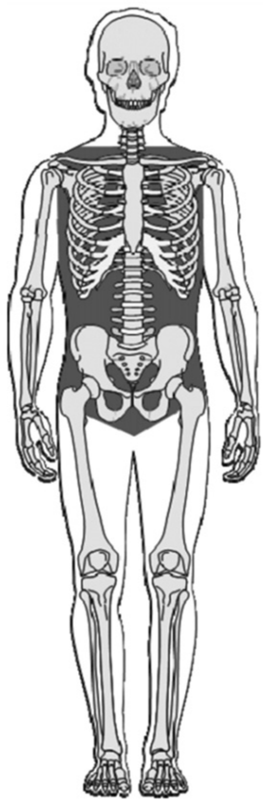

Fig. 1. The shaded area denotes the region where noncompressible torso hemorrhage is anatomically located. (*From* Blackbourne LH, Czarnik J, Mabry R, et al. Decreasing killed in action and died of wounds rates in combat wounded. J Trauma Inj Infect Crit Care 2010;69(1):S1; with permission.)

hemorrhage (NCTH). Civilian studies demonstrating that NCTH accounts for 60% to 70% of mortality following otherwise survivable injuries (ie, no lethal head or cardiac wounds) clearly emphasizes the lethality of this injury pattern.[1,2] Hemorrhage is also a significant problem in the wartime setting, accounting for up to 60% of deaths in potentially survivable injury scenario.[7,8] Studies on those killed in action in Afghanistan and Iraq have shown that of deaths occurring in the setting of otherwise survivable injuries,[3] 80% were a result of bleeding from within the torso.[4,5] The distinction between compressible extremity hemorrhage and NCTH is notable. There has been a demonstrable reduction in mortality from extremity injury with a better understanding of its epidemiology and the need to rapidly control hemorrhage with tourniquets and/or topical hemostatic agents.[8] To date, there has been no such reduction in mortality in the setting of NCTH.

DEFINITION

These observations have resulted in a thrust within the combat casualty care research community to better define and classify locations and patterns of NCTH. Despite its obvious significance, until the wars in Afghanistan and Iraq a consensus definition of NCTH was lacking. Recently reports have emerged from the military's Joint Trauma System and select civilian institutions proposing a unifying classification of this injury pattern. It has been the aim of these studies to establish a cohesive definition allowing for study of the epidemiology of this problem and comparison of management strategies, in hopes of reducing mortality. Until these recent reports, studies of injuries within the torso focused on specific organ injuries such as a series of liver injuries or fell along specialty boundaries such as a vascular surgeon's approach to iliac artery repair.

The wartime perspective on NCTH works from the premise that vascular disruption with bleeding can arise from an array of anatomic sites:

- Large axial vessels
- Solid organ injuries
- Pulmonary parenchymal injuries
- Complex pelvic fractures.

As such, the contemporary definition of NCTH begins with the presence of vascular disruption from 1 or more of 4 anatomic categories listed in **Table 1**. Cardiac wounds are not included within this definition, given their high mortality.

To identify only patients with active hemorrhage from these anatomic categories, the definition of NCTH includes the presence of physiologic measures or operative procedures that reflect hemodynamic instability and/or the need for urgent hemorrhage control. These include hypotension or shock and the need for emergent laparotomy, thoracotomy, or a procedure to manage bleeding from a complex pelvic fracture.

Table 1
Noncompressible torso hemorrhage (NCTH)

Anatomic Criteria	Hemodynamic/Procedural Criteria
1. Thoracic cavity (including lung)	
2. Solid organ injury ≥grade 4 (liver, kidney, spleen)	Hemorrhagic shock[a]; or need for immediate operation
3. Named axial torso vessel	
4. Pelvic fracture with ring disruption	

[a] Defined as a systolic blood pressure <90 mm Hg.

Absent the physiologic or procedural inclusion criteria, the definition of NCTH would be prone to include injuries with the at-risk anatomic category that were not actively bleeding. This article reviews the military and civilian experience with noncompressible torso hemorrhage, and provides an overview of surgical and resuscitative strategies.

MILITARY AND CIVILIAN PERSPECTIVES

One of the first studies to recognize the importance of uncontrolled truncal was by Holcomb and colleagues,[5] who reviewed autopsy findings of special operations forces personnel killed early in the wars in Afghanistan and Iraq, between 2001 and 2004. A panel of experts reviewed the records of 82 fatalities and judged them as nonsurvivable (eg, lethal head or cardiac wounds) or potentially salvageable. This study was one of the first to specifically use the term "noncompressible truncal hemorrhage," although it was not specifically defined. NCTH was found to be the cause of death in 50% of patients judged to have sustained potentially survivable injuries.

Kelly and colleagues[4] used a similar methodology to analyze 997 United States military deaths that occurred within 2 time periods: 2003 to 2004 and 2006. Hemorrhage was the leading cause of death in those with otherwise survivable injuries, and accounted for 87% and 83% of deaths during these respective periods. Airway problems, head injury, and sepsis constituted the remaining causes of death.

Within the hemorrhage group, 50% were due to NCTH and 33% to extremity hemorrhage (amenable to tourniquet application). This study also introduced hemorrhage from another distinct anatomic and clinically important location: junctional areas between the torso and the extremities. Junctional vascular injury or hemorrhage from the proximal femoral or axillobrachial vessels is often not amenable to direct pressure or application of a tourniquet, and therefore poses an especially difficult problem. In the study by Kelly and colleagues,[4] 20% of deaths from hemorrhage occurred from injuries to these junctional zones. Again, in these early studies from the war, NCTH was not explicitly defined but encompassed disruption of any torso-associated vascular structure or viscera.

It is interesting that these figures remained unchanged when Eastridge and colleagues[6] expanded this analysis to all US military personnel who died of wounds between 2001 and 2009. While lethal head injury was the dominant pattern of trauma in the nonsurvivable cases, hemorrhage again accounted for 80% of potentially survivable deaths. Truncal hemorrhage accounted for 48% of deaths in this cohort of casualties. The publication of these studies provided an important characterization of battlefield injury, and illustrated the high and early lethality of NCTH in those who could have otherwise survived their injuries. In parallel with postmortem studies, several clinical studies have examined the incidence of hemorrhage in particular organ systems.

In a study using the US Joint Theater Trauma Registry (JTTR), White and colleagues[9] reported the incidence of vascular injury in US troops between 2002 and 2009. The investigators observed a specific vascular injury rate of 12% (1570 of 13,075), which was 5 times higher than that described in previous wartime reports. Named large vessel injury accounted for 12% of the torso vascular injuries in this study, with iliac, aortic, and subclavian vessels being the most commonly injured.

In a separate study also using the JTTR, Propper and colleagues[10] examined wartime thoracic injury from 2002 to 2009. The investigators found that thoracic injury of any type occurred in 5% of wartime casualties. In this cohort, mean Injury Severity Score (ISS) was 15 and crude mortality was 12%. The most common thoracic injury pattern in this study was pulmonary contusion (32%), followed by hemopneumothorax (19%).

A report by Morrison and colleagues[11] from a single combat support hospital in Afghanistan analyzed 12 months of consecutive episodes of abdominal trauma. More than half (65 patients, 52.0%) required immediate laparotomy, with hemorrhage from solid organs identified in 46 patients (70.8%). There were 15 deaths (23%) in patients undergoing immediate laparotomy, with a median New ISS of 29 and range of 1 to 67.

Despite the value of these studies, they do not specifically emphasize the potential lethality from vascular disruption resulting in NCTH. In this context and given the undeniable association of NCTH with early mortality in those with otherwise survivable injuries, military researchers and civilian collaborators have aggressively sought to establish a unifying definition of this injury pattern. **Table 1** shows the initial definition of NCTH developed at the US Army's Institute of Surgical Research, which is based on the previously mentioned anatomic categories of vascular disruption linked to either a physiologic or procedural criterion. A procedure in this definition is defined as an emergent laparotomy, thoracotomy, or procedure undertaken to control bleeding from a complex pelvic injury.

EPIDEMIOLOGY OF NONCOMPRESSIBLE TORSO HEMORRHAGE

A recent study of the US JTTR presented at the American Association for the Surgery of Trauma in 2011 used the definition presented in **Table 1** to characterize the epidemiology of NCTH in patients injured in Iraq and Afghanistan between 2002 and 2010. Using the injury pattern criteria alone, 1936 patients were identified as having an injury putting them at risk for NCTH, which was nearly 13% of battle-related casualties. When the physiologic and procedural inclusion criteria were applied to this cohort, 331 patients with a mean ISS $\pm$ SD of 30 $\pm$ 13 were identified as having NCTH. The most common pattern of hemorrhage was pulmonary parenchyma (32%), followed by bleeding from a named, large vessel within the torso (20%). High-grade solid organ injury (grade IV or V liver, kidney, or spleen) also constituted 20% of cases, and pelvic fracture with vascular disruption accounted for 15%. The most lethal injury pattern (odds ratio; 95% confidence interval) in this study was that to a named large vessel within the torso (3.42; 1.91–6.10), followed by injury to the pulmonary parenchyma (1.89; 1.08–3.33), and complex pelvic fracture with vessel disruption (0.80; 0.36–1.80).

The same investigators applied this definition to British troops injured in Iraq and Afghanistan from 2001 to 2010 using the United Kingdom's Trauma Registry. This analysis included patients who died before receiving treatment at a military surgical hospital (ie, killed in action) and thus did not apply the physiologic or procedural inclusion criteria. This report identified 234 patients with the anatomic injury profile at risk for NCTH, which was 13% of UK battle-related injuries, a number nearly identical to the incidence of this injury pattern in the US JTTR. The overall case fatality rate of UK patients with NCTH was 83%, compared with 25% for any battle-related injury, underscoring the significant mortality burden posed by vascular disruption of any type within the torso.

The civilian experience with NCTH carries a similar message, albeit with a different injury pattern. Specifically, vascular injury or disruption within the torso in the civilian population consists predominantly of blunt rather than penetrating or explosive mechanisms.[2] Hemorrhage remains the leading cause of potentially preventable death in civilian settings, accounting for 30% to 40% of mortality, with 33% to 56% of such deaths occurring in the prehospital phase of injury.[1] Tien and colleagues[12] examined 558 consecutive trauma deaths at a Canadian level-I trauma center. While the most numerous cause of death was related to central nervous system injury, 15% were

due to hemorrhage, with 16% of such deaths judged to be preventable. Delay in identifying the bleeding source was cited as the most common preventable reason, with pelvic hemorrhage the most common source. These findings were confirmed and extended by investigators at Los Angeles County + University of Southern California Medical Center, which identified delayed pelvic hemorrhage control as the most frequent cause of preventable deaths from hemorrhage.[13]

CLINICAL MANAGEMENT STRATEGIES IN TORSO HEMORRHAGE CONTROL

The aim of this section is to provide a summary of tools and adjuncts available for the control of torso hemorrhage within the context of current literature. Despite advances in surgical understanding, technique, and technology, one fundamental tenet remains: proximal and distal control are essential when managing suspected vascular injury.

Damage-Control Surgery and Damage-Control Resuscitation

Damage-control surgery (DCS) is a surgical strategy originally described in the context of exsanguinating abdominal trauma, whereby the completeness of operative repair is sacrificed to limit physiologic deterioration.[14,15] This technique has been extended to include other body regions.[16] Definitive operative repair is then completed in a staged fashion following resuscitation and warming in the intensive care unit. DCS is an extreme surgical strategy that carries a risk of infection; intra-abdominal abscess, wound dehiscence, incisional hernia, and enterocutaneous fistulas are common.[17–19] Consequently, this approach should only be used in select patients, as discussed in the review by Chovanes and colleagues elsewhere in this issue.

Military experience in Iraq identified a survival benefit in patients receiving a higher ratio of packed red blood cells (PRBC) to fresh frozen plasma (FFP), who had a significantly lower mortality than patients receiving the lower ratio (19% vs 65%; $P<.001$).[20] This finding has brought about the concept of a balanced or hemostatic resuscitation whereby major trauma patients are resuscitated with a unit ratio of around 1:1 PRBC to FFP. This concept has evolved into a coherent strategy incorporating additional hemorrhage-control adjuncts and is termed damage-control resuscitation (DCR).[21] Most DCR protocols incorporate techniques such as permissive hypotension, minimal use of crystalloid, aggressive warming, and novel infusible hemostatic drugs such as tranexamic acid, paired with DCS for early hemorrhage control.[22]

It is important that DCS should be considered a tool within DCR, which may be used in circumstances of extreme physiology or significant anatomic injury burden.[23] The evidence thus far suggests that the adoption of DCR confers a survival advantage, and is associated with a reduction in the use of DCS techniques.[18,24,25] The specific elements of DCR are well reviewed by Cohen elsewhere in this issue.

However, although DCR demonstrates significant promise, it does liberally use precious resources exposing patients to the risks associated with blood products. Work is being undertaken on product ratios[26,27] and the use of novel compounds to reduce this reliance, such as lyophilized fibrinogen and platelets.[28]

Resuscitative Surgical Maneuvers

A proportion of patients with NCTH present with circulatory collapse, either profoundly hypotensive or in cardiac arrest. Management of patients presenting in such a fashion has been extensively studied.[29–32] The current civilian standard of care is to perform a resuscitative thoracotomy (RT), which permits the following maneuvers[33]:

- Release of cardiac tamponade
- Management of thoracic bleeding

- Control of massive air-leaks
- Internal cardiac massage
- Thoracic aortic occlusion.

The latter maneuver is undoubtedly the most practiced, as aortic control theoretically enhances cerebral and myocardial perfusion.

Although RT is typically performed for thoracic wounding, it has been explored for use in patients with a tense hemoperitoneum in physiologic distress.[34,35] The aim is to obtain control of the vascular inflow of the abdomen while enhancing central pressure, before laparotomy and abdominal hemostasis. This approach is now being challenged because of its poor survival rate, although the physiologic principle of aortic occlusion supporting central pressure remains.

Resuscitative techniques whereby proximal control is remote to the site of injury should not be used liberally, as direct vascular control, when possible, results in a lesser ischemic burden. A recent animal study examined thoracic clamping versus aortic clamping versus direct control of an iliac arterial injury identified a significantly reduced burden of global ischemia with direct control.[36]

Aortic occlusion can also be achieved by endovascular balloon occlusion, as demonstrated by the use of percutaneous devices used to control the neck of abdominal aortic aneurysms during endovascular repair.[37,38] This technique enables the physiologic benefit to be realized without the additional burden of entering a body cavity. Such a technique has been used in trauma as early as the Korean War[39] and since.[40] To date, it has not been used widely or systematically evaluated. However, with recent improvements in endovascular devices and resuscitation in general, there is a renewed interest in this approach, which has been termed resuscitative endovascular balloon occlusion of the aorta (REBOA).[41]

Recent animal work has characterized the reduced physiologic burden of REBOA compared with RT.[42] Animals in class IV shock were allocated to aortic occlusion by a balloon or clamp via thoracotomy. The balloon group demonstrated the same improvement in mean aortic pressure as the clamp group, but with a lower lactate, base excess, and pH measurements after intervention. A different group has identified 40 minutes as the optimum time for aortic balloon occlusion in hypovolemic animals using similar end points.[43]

Operative Exposures in Noncompressible Torso Hemorrhage

The majority of patients with these types of injuries qualify for management in a damage-control fashion, and the appropriate surgical maneuvers depends primarily on the location of hemorrhage within the torso. Certain techniques are described well by Chovanes and colleagues in this issue.

Thorax

For hemorrhage control within the thoracic cavity, access to the ipsilateral side is best via an anterolateral thoracotomy, through the fourth interspace, with the patient in the supine position, tilted up on a roll (**Fig. 2**). This approach also allows extension of this incision across the sternum into the right hemithorax or the clam-shell incision, permitting access to either of the other 2 compartments in the chest (mediastinum and contralateral thoracic cavity) if required (**Fig. 3**). It is important that a surgeon performing this maneuver must also have the ability to concomitantly explore the abdomen, so this must be included when preparing the surgical field.

Once within the chest, hemorrhage control is the priority. Pulmonary bleeding can be controlled using several techniques, depending on location. Injury to the periphery

Fig. 2. Anterolateral thoracotomy through the fourth intercostal space permitting access to the left hemithorax, aorta, and cardiac structures. (*From* Hirshberg A, Mattox KL. The no nonsense trauma thoracotomy. In: Top knife. Shrewsbury: TFM Publishing Ltd; 2005. p. 160. © January 2005, Asher Hirshberg MD & Kenneth L. Mattox MD; with permission from TFM Publishing Ltd. [www.tfmpublishing.com]).

of the lung can be stapled off in a nonanatomic fashion using a linear stapler. Bleeding from within a wound tract is effectively managed following tractotomy, whereby a linear stapler or clamp is introduced down the length of the wound tract and then deployed. This action opens the tract, permitting direct oversewing of disrupted vessels using 3-0 or 4-0 polypropylene sutures on a larger tapered needle (eg, SH) or control with a stapling device.

If hemorrhage from the lung is from the deeper hilar structures, the lung itself (after mobilization) can be compressed or even twisted on itself to occlude the hilar vessel.

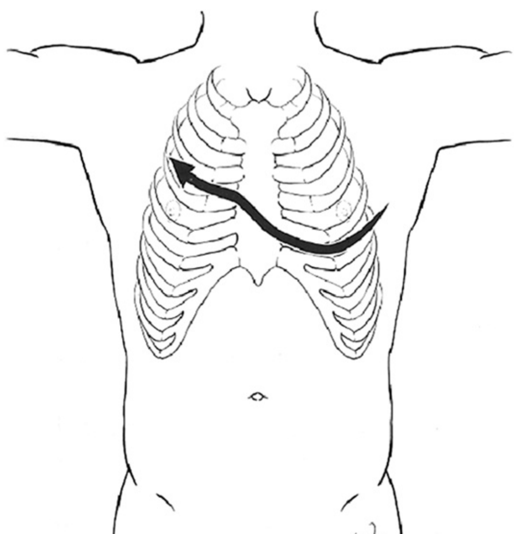

Fig. 3. Extension of the anterolateral thoracotomy across the sternum into the right intercostal space, facilitating access to the mediastinum and right hemithorax. (*From* Hirshberg A, Mattox KL. The no nonsense trauma thoracotomy. In: Top knife. Shrewsbury: TFM Publishing Ltd; 2005. p. 161. © January 2005, Asher Hirshberg MD & Kenneth L. Mattox MD; with permission from TFM Publishing Ltd. [www.tfmpublishing.com]).

Because such a hilar twist results in a physiologic burden similar to a pneumonectomy (ie, significant elevation in right heart afterload), it should be performed only as a last resort. In cases where the injury significantly compromises a patient's pulmonary reserve, extracorporeal life support (ECLS) may also be a useful adjunct.[44]

Abdomen

The abdomen should be opened through a midline incision from the xiphoid process to the pubic symphysis to permit access to all 4 quadrants. Initial packing remains the best method of initial hemostasis, allowing for the resuscitation to restore the circulating volume. An additional useful adjunct for patients in extremis is resuscitative aortic occlusion of the aorta at the diaphragmatic hiatus. The next key step is sequential evaluation of the abdomen and a decision regarding local control of hemorrhage and contamination.

Hemorrhage from the solid organs of the abdomen is managed differently, depending on the organ in question. Exposure and removal of the spleen is fairly straightforward and well tolerated by the patient, and thus splenectomy is the favored maneuver for the hemorrhaging spleen.

By contrast, hemorrhage from the liver necessitates packing to control venous bleeding in most instances. Control of the porta hepatus at the gastrohepatic ligament and application of the Pringle maneuver is often used as an adjunct to liver packing to control inflow to the organ. Depending on the nature of the wound and the location of the hepatic bleeding, the liver can be mobilized by dividing the coronary and triangular ligaments and allowing the left and right lobes to be drawn or compressed together. If this maneuver is successful, a Vicryl mesh can be used to wrap the liver and maintain apposition of the lobes for hemostasis. If the bleeding liver wound is a defined tract, a tractotomy can be performed to allow exposure and ligation of specific vessels deeper within the wound, or a Penrose drain can be tied over a nasogastric tube to allow inflation of the Penrose within the tract and application of a balloon tamponade.

Mesenteric vessels can be controlled by Forgarty thrombectomy balloons, inserted proximally through small to mid-sized vessels and inflated for proximal control in some cases. Collateral flow to the bowel is generally robust, and ligation of branches of the superior mesenteric artery distal to the middle colic artery is often tolerated. Similarly, proximal branches of the celiac artery or the artery itself can be ligated as a damage-control maneuver with serial observation of the bowel. If the superior and inferior mesenteric and internal iliac arteries are patent and uninjured, ligation of proximal celiac artery branches or the celiac artery itself is often tolerated. Although temporary vascular shunts are mainly used in extremity vessels, there are case reports of their application to mesenteric vessel injuries.[45]

Retroperitoneum

Posterior to the peritoneal sac lies the retroperitoneum, which can be divided into 4 zones. Zone I is centrally located and contains the aorta and inferior vena cava (IVC). Hemorrhage often manifests as a hematoma and should always be explored in this zone. Management of such injuries should adhere to standard principles of proximal and distal control of the vessel. The aorta can be widely exposed through a left medial visceral rotation (the Mattox maneuver, **Fig. 4**) by mobilizing the left colon and kidney. The IVC can be explored through a right visceral rotation (the Cattel-Braasch maneuver, **Fig. 5**), mobilizing the large and small bowel fully to the root of the mesentery.

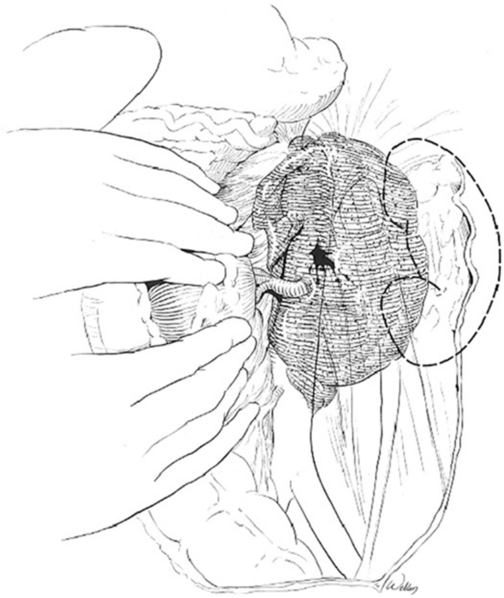

Fig. 4. The left medical visceral rotation (the Mattox maneuver) where the left colon and kidney are mobilized to permit access to the aorta and left sided retroperitoneal structures. (*From* Hirshberg A, Mattox KL. The no nonsense trauma thoracotomy. In: Top knife. Shrews bury: TFM Publishing Ltd; 2005. p. 63. © January 2005, Asher Hirshberg MD & Kenneth L. Mattox MD; with permission from TFM Publishing Ltd. [www.tfmpublishing.com]).

Approaching large-vein injuries in the abdomen is often more challenging than controlling and repairing arterial hemorrhage. Like bleeding from large arteries, one must be prepared with multiple suction devices and a good retraction device, and be sure that the anesthesia team is prepared with warmed rapid transfusion devices. Because large veins often do not tolerate clamps in the setting of trauma and hematoma, direct pressure should be applied with sponge-sticks or the smaller Kittner dissector sponges. These devices substitute for manual pressure and allow one to create more visibility in the operative field.

In situations of large-vein injuries, one should prepare to use a larger tapered needle (eg, SH) on 4-0 polypropylene suture. Larger needles are necessary to see and manipulate within the copious amounts of dark blood that pool between placement of the sutures. Using needles that are too small or suture that is too fine is often frustrating, and results in tearing of the vein and worsening of the injury. When approaching the vena cava or iliac veins one must also be cognizant of the posterior lumbar or lumbosacral branches, which are often quite large and not visible from the anterior approach. If the defect in the vena cava or iliac veins is large enough to cause a greater than 50% narrowing on primary repair, the option of shunting or ligation should be considered.

Zone II is perirenal in location and generally should be managed conservatively in blunt trauma, provided there is no expansion and the patient is hemodynamically stable. Penetrating trauma requires a different approach, with an emphasis on exploration and repair of the kidney if possible, or nephrectomy. If there is concern of injury to or violation of the collecting system, drains should be left in the perinephric or retroperitoneal space.

Fig. 5. The right medical visceral rotation (the Cattel Braasch maneuver) whereby the right colon and duodenum is mobilized to the base of the small bowel mesentery to permit access to the inferior vena cava and right sided retroperitoneal structures. (*From* Hirshberg A, Mattox KL. The no nonsense trauma thoracotomy. In: Top knife. Shrewsbury: TFM Publishing Ltd; 2005. p. 67. © January 2005, Asher Hirshberg MD & Kenneth L. Mattox MD; with permission from TFM Publishing Ltd. [www.tfmpublishing.com]).

Zone III originates from within the pelvis, although these injuries can be extensive, tracking all the way up to the supracolic compartment. Pelvic hematomas are best managed conservatively in blunt trauma, and opening them should be avoided. Further management options are outlined below. In penetrating, vascular control is vital, especially if a direct vessel injury is suspected, and may require mobilization of the terminal aorta.

Operative management of bleeding from the portal-retrohepatic zone (sometimes referred to as Zone IV) is fraught with difficulty. Control of bleeding from the retrohepatic vena cava is especially challenging and is associated with high mortality. Contained hematomas should be left undisturbed, and expanding lesions should be packed in the first instance.

Pelvis

The pelvis is a complex compartment containing several unique anatomic structures typically managed in the elective setting by specialists from a range of disciplines (eg, urology, orthopedic surgery, vascular surgery, and general/colorectal surgery). Operative exposure of the pelvic space can be achieved through either a transperitoneal

approach at the time of laparotomy or with an extraperitoneal approach, which can be accomplished through a midline or a Pfannenstiel incision. The former is the quicker approach, enabling access to both the abdomen and the pelvis and permitting access to the aorta and distal vascular along with the hollow viscera within that region. The extraperitoneal approach allows access to the external iliac vasculature for suprainguinal arterial control and for packing of the preperitoneal space (**Fig. 6**). The latter is a useful adjunct to managing venous bleeding in complex pelvic fractures once boney stabilization has been achieved.

Arterial bleeding from the pelvis is most commonly managed with endovascular techniques such as coil embolization in cases of complex pelvic fracture. In rare instances of pelvic fracture or open fragmentation or gunshot wounds to the pelvis, ligation of the internal iliac artery is necessary as a hemorrhage-control maneuver. Because of cross-filling from the contralateral internal iliac artery, ligation of one side must typically be accompanied by packing with or without topical hemostatic agents to achieve hemostasis. Ligation of both internal iliac arteries is rarely necessary and is associated with very poor outcomes, related both to the complex nature of the wound and to the subsequent pelvic, buttock, and peroneal ischemia.

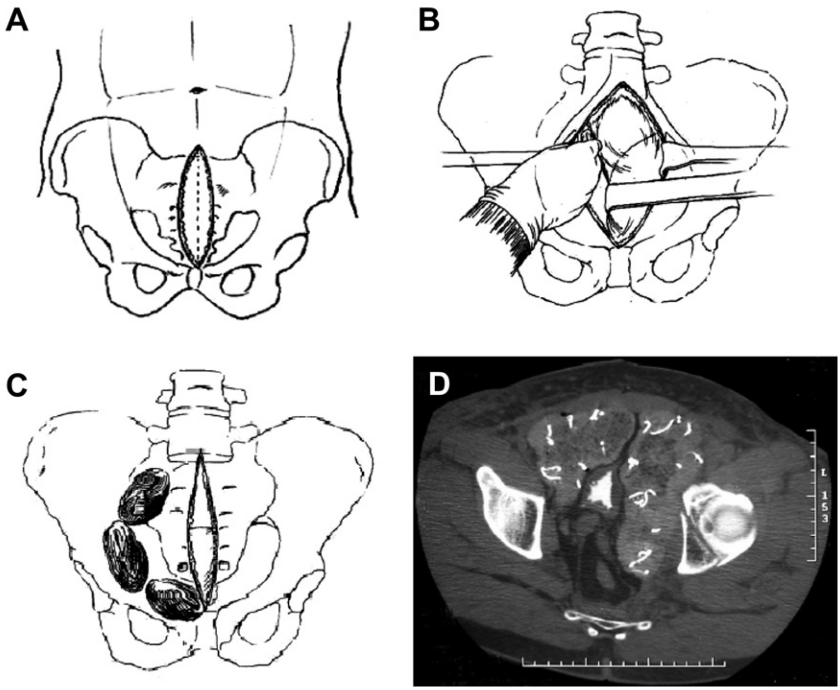

Fig. 6. The sequence of preperitoneal pelvic packing. (*A*) A lower midline incision down to the peritoneum. (*B*) Blunt dissection of preperitoneal space. (*C*) Packing of the preperitoneal space. (*D*) A representative computed tomography scan demonstrating the packs in situ. ([*A C*] *From* Cothren CC, Osborn PM, Moore EE, et al. Preperitoneal pelvic packing for hemodynamically unstable pelvic fractures: a paradigm shift. J Trauma 2007;62(4):836; with permission; [*D*] *From* Totterman A, Madsen JE, Skaga NO, et al. Extraperitoneal pelvic packing:a salvage procedure to control massive traumatic pelvic hemorrhage. J Trauma 2007;62(4):845; with permission).

PUTTING IT ALL TOGETHER: CURRENT APPLICATIONS AND FUTURE DIRECTIONS

NCTH will continue to challenge clinicians, and future research strategies require a novel approach to reduce the mortality of this injury complex. The first step requires recognition and characterization of the problem, best served by a unifying definition enabling investigators to compare true like with like. Efforts to develop such a definition are under way in both military and civilian settings. In addition, it is important to characterize not only mortal injury patterns in relation to NCTH but also the temporal distribution of deaths. With this approach, both prehospital and hospital interventions can be developed appropriately.

The identification and quantification of specific injuries will allow a tailoring of resuscitation strategies. Meanwhile, several promising new technologies designed to facilitate the management of NCTH are emerging. As an example, REBOA has been discussed already in the context of early animal work, and this technique is now starting to appear in clinical practice. It is also very important that this transition from preliminary evidence to clinical application be done in such a way that reliable data can be captured to ensure robust analysis of its clinical impact.

REBOA is one example of how endovascular approaches may offer novel solutions to difficult problems in trauma care. Expansion of other endovascular or minimally invasive approaches will only continue with traditional elective techniques being used and modified for trauma. This aspect is epitomized by the advent of the Hybrid Operating Room, where physicians can seamlessly change approach from operative to endovascular and vice versa without having to change location.[46,47] This approach may prove to be exceptionally useful in junctional trauma, such as in the pelvis, where approaches are often performed in parallel.

Yet further in the future is the potential application of ECLS[44,48] in combination with hypothermia for patients who suffer a traumatic arrest from NCTH. Following promising animal data and human evidence from nontraumatic cardiac arrest, a multicenter trial of ECLS with deep hypothermia for the management of polytrauma patients has been conceived.[49] The application of this technology theoretically reduces metabolic demand and extends the time frame within which a surgeon must achieve hemorrhage control. In addition to active thermoregulation, the extracorporeal circuit can be used for resuscitation access and the introduction of agents to ameliorate reperfusion injury, among other functions.

SUMMARY

Vascular disruption with concomitant hemorrhage is the leading cause of potentially preventable death in both civilian and military trauma. NCTH is a particularly challenging entity which, despite being an intuitive concept, lacks a formal definition. Management requires rapid decision making, aggressive resuscitation, and surgery with an emphasis on early hemostasis. Despite the emergence of DCR and adjuncts such as endovascular surgery, the principles of proximal and distal control remain.

The use a novel and inclusive definition of NCTH based on anatomic and physiologic criteria should enable better identification of this important patient population and enable comparisons of treatment modalities in the future.

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